Ultrahigh-Velocity Railgun

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A railgun is a very simple device, essentially a single-turn coil (Fig. 1). Electric current is sent down one rail, through the moveable armature, and returns down the other rail. The magnetic "pressure" developed in the railgun bore behind the armature creates a driving force to accelerate it down the rails. For speeds less than about 2.5 km/s, designs typically use a solid armature made of aluminum. At speeds higher than that plasma forms, and therefore either a hybrid armature (solid armature with plasma brushes) is used, or the solid portion of the armature is eliminated *a priori* and a plasma armature is allowed to form.

During the late 1980's, Lawrence Livermore National Laboratory took a leading role in the development of railguns as a means of launching projectiles at ultrahigh velocities, *i.e.*, > 8 km/s. A practical ultrahigh-velocity (UHV) railgun would have contemporary applications in equation-of-state research, space launch, and kinetic energy weapons.

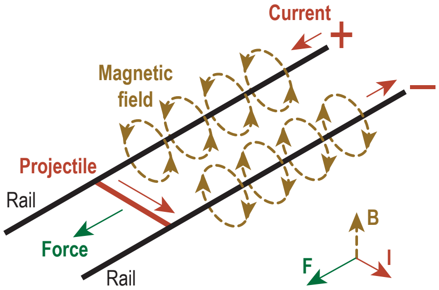

Figure 1. Basic railgun physics. I is the current; B is the magnetic field; and F is the resultant Lorentz force. Maximum efficiency occurs when the current is concentrated at the rear of the projectile.

Our UHV railgun project aims to understand the physics that currently limits railgun performance, by leveraging the history of railgun development with our world-class leadership in modeling and simulation.

Project Goals

Today's railgun technology is limited by poorly understood mechanisms at velocities between 5 and 6 km/s. The most commonly accepted mechanism for this poor performance is "restrike," defined as the short-circuiting of the main current path at a distance significantly behind the armature. The ultimate cause of restrike has been variously attributed to viscous/ablative drag, thermally-driven avalanche, or 3-D MHD effects (Fig. 2). Progress toward isolating the mechanisms had been impeded by the limited simulation and diagnostic capabilities available in the 1980's when most railgun tests were conducted.

This project aims to overcome these twin hurdles, by 1) developing ALE3D as a useful tool for the simulation of UHV railguns; and 2) performing experiments adequate to verify the capability of ALE3D in railgun-relevant regimes.

Ultimately, an understanding of the limiting physics of railguns could lead to candidate railgun designs capable of generating projectile velocities above 8 km/s.

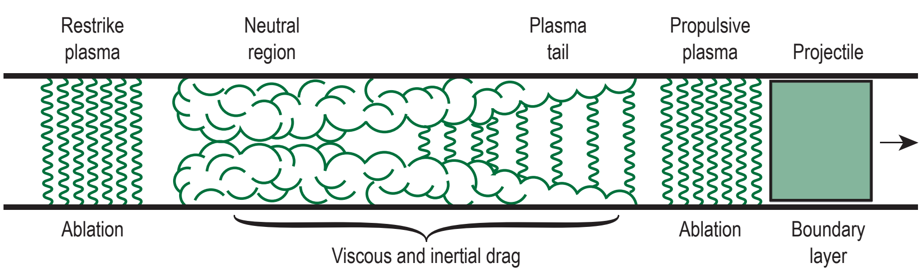

Figure 2. Restrike Hypothesis. The restrike plasma short-circuits the propulsive plasma, resulting in a reduction in the Lorentz force.

Relevance to LLNL Mission

The development of a 3-D modeling capability tool for materials in the warm-dense-matter regime characteristic of railgun plasmas, including the physics of melt and transition to the ionized state, has a wide range of application within the Laboratory's mission. Related applications include the modeling of exploding detonator bridge wires, explosive pulsed power applications, and arc welding/cutting. Diagnostic techniques developed and used in the validation experiments have similar applications.

A UHV railgun that exceeds current velocity limits would be well-suited to high-velocity impact-driven equation-of-state experiments, for which the present technology (two-stage gas guns) has limitations above 8 km/s.

FY2007 Accomplishments and Results

We augmented ALE3D with plasma conductivity models, primarily from the Laboratory's Purgatorio code, and SESAME conductivity models from Sandia National Laboratories. Validation studies comparing ALE3D to the legacy 2-D code CALE began. Both CALE and ALE3D were used to design the Fixed Hybrid Armature experimental facility (Figs. 3 and 4).

The Fixed Hybrid Armature test facility was constructed leveraging legacy hardware from the early 1990's. In this experiment, a railgun with the hybrid armature held in place is coupled to a long-pulse power source. Two plasma brushes are initiated from exploding aluminum foils. Since no gross motion of the armature occurs, this experiment allows detailed analysis of the plasma behavior,

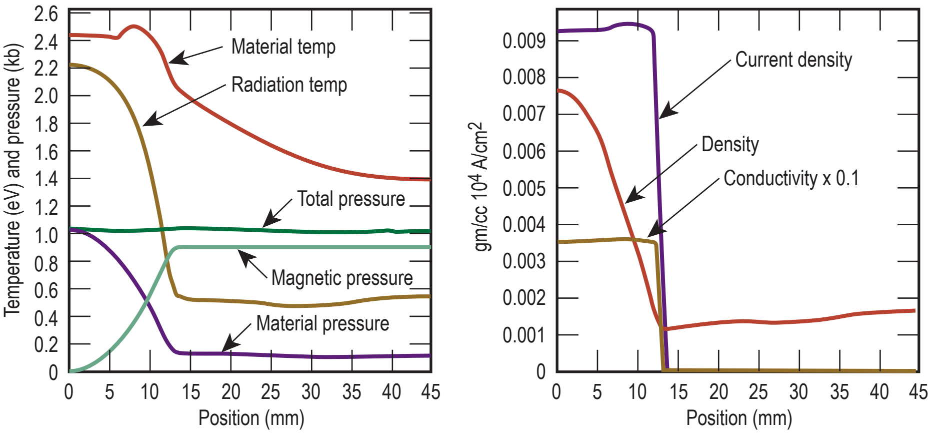

Figure 3. 2D CALE Fixed Armature Simulations, used both as a reference for ALE3D development and to help design the Fixed Armature Experiment.

Figure 4. ALE3D Fixed Armature Simulations. The aluminum in light blue has exploded and is being contained by magnetic pressure against the insulator wall (pink).The red bars are the rails; the dark blue is the air.

including measurements of currents and magnetic fields, plasma pressure, and various optical diagnostics.

The experiment (Fig. 5) permits investigation of armature plasma dynamics due to both ablation and high plasma ejection speeds, as well as investigating near steady-state conditions. Diagnostics includes a fine array of B-dots for the magnetic field, Rogowski coils for currents, and piezo-electric pressure sensors. Fiber optics captured the light emission data in preparation both for future use of fiber-optic-based pressure sensors and for optical techniques to measure the plasma emission characteristics as a function of time and position.

We initiated a project with the U.S. Navy for modeling and simulation efforts that focus on a different portion of the mass/velocity space. This effort aims to replace conventional ship-based artillery with electrically launched kinetic energy weapons.

Related References

1. Hawke, R. S., *et al.*, "Measurements of Experimental Plasma Brush Behavior in Hybrid Armatures," *IEEE Transactions on Magnetics* **29**, 1, pp. 814-818, 1993.
2. Crawford, R., D. Keefer, and R. Tipton, "Velocity Limiting Magnetohydrodynamic Effects in Railgun Plasma Armatures," *IEEE Transactions on Magnetics*, **29**, 1, pp. 781-786, 1993.
3. Boyton, G. C., *et al*., "Secondary Arcs in 2-D MHD Numerical Simulations of EML Plasma Armatures," *IEEE Transactions on Magnetics* **31**, 1, pp. 564-569, 1995.
4. Parker, J. V., "Why Plasma Armatures Don't Work (and What Can Be Done About It)," *IEEE Transactions on Magnetics* **25**, 1, pp. 418-424, 1999.

FY2008 Proposed Work

Simulation efforts will focus largely on improving and understanding ALE3D as it applies to railgun physics. This will include further comparisons with CALE and application to railguns with moving armatures. Ultimately, the goal is to model legacy LLNL railgun experiments with a view toward understanding the observed velocity limitations.

The Fixed Hybrid Armature experiments will continue. A number of diagnostics will be fully vetted within the context of the experiment. Ultimately, the results of these experiments will be used to increase confidence in the simulation results.

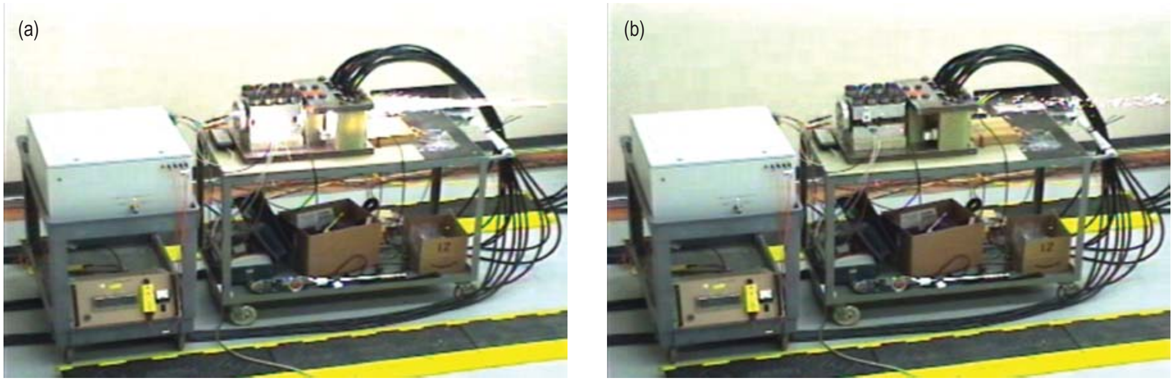

Figure 5. Fixed Armature Experiment Shot 1, 290 kA. (a) As the aluminum foils explode, part of the plasma is lost out the back of the experiment. (b) The remainder is contained by the magnetic forces, and forms plasma brushes that conduct current through the fixed armature.